

***Blood Flow Restriction Training as a Rehabilitative Tool for Anterior
Cruciate Ligament Reconstruction Patients***

An Honors Thesis (HONR 499/AT 461)

by

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Abstract

Injuries to the anterior cruciate ligament in athletic populations are frequent, with roughly 150,000 occurring each year. Anterior cruciate ligament reconstruction (ACLR) using an autograft is the most common option to regain function, indicating months of rehabilitation with an early focus on preventing atrophy of the quadriceps muscles and restoring extensor strength in order to regain function and long term functional outcomes. Unfortunately, exercises utilized to increase extensor strength can place significant shear stress on the recovering joint and healing tendon graft. One promising technique to decrease this stress is through low pressure vascular occlusion combined with low load resistance training. Some studies have shown that this style of Blood Flow Restriction (BFR) training can produce similar strength gains to high resistance training alone, indicating its application for post-operative knee conditions, especially ACLR. This type of training is poorly understood but is thought to utilize cell swelling and oxidative stress in which fast twitch muscle fibers are more readily recruited as well as an increased presence of metabolic compounds associated with muscle growth such as cytokine and growth hormone. A literature review was conducted to assess and analyze current data on the subject, finding 4 well designed studies relevant to the topic. Implications for further research and practical application were drawn from these studies.

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I would also like to thank my family, friends and fraternity for giving me a safety net to fall back on when times were rough and projects like this seemed impossible.

Process Analysis Statement

For my thesis I plan to complete an extensive literature review over the topic of blood flow restriction training – a new technique that emerged within the sports performance world and is now starting to be applied in rehabilitative settings like physical therapy or athletic training. Blood Flow Restriction Training(BFR) is a technique where a tourniquet like device is applied to the proximal extremity and inflated or tightened until the majority of arterial blood flow to a limb is cut off – creating an atmosphere low in oxygen and high in deoxygenized blood and related metabolic compounds. The use of this training claims to be able to achieve significant muscular gains while utilizing a much smaller resistance stimulus than traditional high resistance strength training. This is an important technique for rehabilitation, especially for the anterior cruciate ligament(ACL) as many of the most important exercises early in the rehabilitation process apply significant amounts of shear stress to the recovering joint and tendon graft – making BFR a prime candidate for patients and clinicians alike.

My literature search will use many of the databases provided by Ball State University, trimming results by using inclusion and exclusion criteria as well as Boolean search terms to find the best evidence possible -preferably randomized control trials or other well designed studies that can be appraised and evaluated to build my report on. This literature review will be presented as a Critically Appraised Topic(CAT) following the guidelines posted by the Journal of Sports Rehabilitation and the American Medical Association; and will include a lengthy discussion over the details of the technique, its effect on the specific muscular and physiological benefits(or lack thereof) and how this information should be considered and applied clinically to the field of athletic training.

Blood Flow Restriction Training as a Rehabilitative Tool for Anterior Cruciate Ligament Reconstruction Patients

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Clinical Scenario:

Injuries to the anterior cruciate ligament in athletic populations are frequent, with roughly 150,000 occurring each year.¹ Anterior cruciate ligament reconstruction (ACLR) using an autograft is the most common option to regain function, indicating months of rehabilitation with an early focus on preventing atrophy of the quadriceps muscles and restoring extensor strength in order to regain function and long term functional outcomes.² Unfortunately, open kinetic chain exercises utilized to increase extensor strength can place significant shear stress on the recovering joint and healing tendon graft.³ One promising technique to decrease this stress is through low pressure vascular occlusion combined with low load resistance training, typically around 30% of an individual's 1 Rep Maximum (1RM). The vascular occlusion is often supplied through an inflatable tourniquet set to provide strong, but not complete vascular occlusion. Some studies have shown that this style of Blood Flow Restriction (BFR) training can produce similar strength gains to high resistance training alone (70%+ 1RM), indicating its application for post-operative knee conditions, especially ACLR.^{4,5} This type of training is poorly understood but is thought to utilize cell swelling and oxidative stress in which fast twitch muscle fibers are more readily recruited as well as an increased presence of metabolic compounds associated with muscle growth such as cytokine and growth hormone.⁶

Focused clinical question:

Does low load resistance training with blood flow restriction effectively improve quadriceps size, strength or pain outcomes in patients undergoing anterior cruciate ligament reconstruction?

Summary of Search, “Best Evidence” Appraised, and Key Findings

4 randomized control trials met the inclusion and exclusion criteria to address the clinical question.⁷⁻¹⁰

One study reported a significant increase in knee extensor strength utilizing BFR when compared to control groups.⁹

Two studies reported an increase in quadriceps size utilizing BFR,^{9,10} while 1 study utilizing intermittent BFR did not.⁸

One study reported a decrease in perceived pain when using low intensity training with BFR compared to a healthy population and a high intensity regiment for ACLR patients.⁷

Clinical Bottom Line

An early summary of evidence suggests BFR may potentially be an effective treatment technique to decrease stress on the knee and pain while achieving significant improvements in strength and muscle activation following ACLR. However the lack of standard procedures for occlusion pressure and time of application make it a difficult technique to implement in practice, especially with limited research on rehabilitative application. The concerns regarding the safety of cheaper commercially available devices adds to this problem, and at the time I cannot recommend BFR over high resistance training for patients recovering from ACLR.

Strength of Recommendation: Grade B evidence shows promising yet inconsistent results regarding the use of blood flow restriction and low intensity resistance training to improve strength, size and pain outcomes in the lower extremity for ACLR patients.

Search Strategy

Search Terms:

- Patients: *post-operative anterior cruciate ligament reconstruction* patients or *ACLR* or *operative*
- Intervention: *Blood flow restriction training* or *vascular occlusion* and *resistance exercise* or *resistance training*
- Comparison: *Low Intensity* or *High intensity resistance training* or *control*
- Outcome: *pain* or *atrophy* or *hypertrophy* or *strength*

Databases Utilized:

- CINAHL
- PubMed
- Cochrane Library
- SportDiscus

Other literature found through reference lists and related article searches

Inclusion and Exclusion Criteria

Inclusion Criteria:

- Studies that utilized low load resistance training with BFR
- Studies must have pain, hypertrophy or strength as primary outcomes
- Participants must be pre- or post-operative ACLR patients
- Studies that were published within the last 10 years (2008-2018 when research began)
- Studies that were published in English
- Studies must be Randomized Control Trials

Exclusion Criteria:

- Studies that examined BFR in post-operative rehabilitation other than ACLR
- Studies that focused solely on metabolic or acute physiological response other than pain, strength or quadriceps size
- Full text unavailable through Ball State University Databases or Interlibrary Loan

Results of the Search:

Rough this search 4 relevant studies were located and categorized as shown in Table 1 (based on Levels of Evidence, Centre for Evidence Based Medicine, 1998)

Table 1 **Summary of Study Design from Articles Retrieved**

Level of Evidence	Study Design	Number Found	Reference
2	Randomized Control Trial	4	Hughes et al. ⁷ Iverson et al. ⁸ Ohta et al. ⁹ Zargi et al. ¹⁰

Best Evidence:

This selection of studies was based on clinically relevant findings that benefit ACLR patients and make up the Clinically Appraised Topic(CAT) in Table 2. They were all given a level of evidence rating of 2 and measured pain, strength or size outcomes in the lower extremity of ACLR patients.

Table 2 **Characteristics of Studies**

	Hughes et al..⁷	Iverson et al..⁸	Ohta et al..⁹	Zargi et al..¹⁰
Design	Randomized Control Trial	Randomized Control Trial	Randomized Control Trial	Randomized Control Trial
Participants	30 participants split into 3 groups; 10 non-injured patients with light resistance and BFR (age 28 ± 5 yr.); 10 ACLR patients randomly allocated to receive light resistance and BFR (age 29 ± 5 yr.); and 10 ACLR patients randomly allocated to receive high resistance and BFR (age 31 ± 7 yr.). All intended to use hamstring autographs with no other ligamentous involvement. No patients had a history of musculoskeletal injury, cardiovascular or metabolic disorder jury for 12 months prior to the study. ACLR patients were included roughly 3 weeks after surgery, once they could perform leg press exercises.	24 participants aged 18-40 were randomized into 2 groups; 12 patients received the BFR protocol (age 24.9 ± 7.4 yr.); and 12 made up the control group. (age of 29.8 ± 9.3 yr.) 7 males and 5 females made up each group. Patients all planned to undergo hamstring autographs within 6 months post ACL injury, and no patients had a history of knee injury or multiple ligaments involved. All patients suffered their injury through sport participation and no other statistical differences were noted.	44 participants aged 18-52 were randomly assigned to 2 groups; 22 received BFR (age 30 ± 9.7) and 22 in the control group (age 28 ± 9.7) 12 males and 10 females were in the first group while 13 males and 9 females were in the second. Hamstring tendon grafts were used for all patients, and all injured their ACL recreationally and had no previous history of knee injury, multiple ligament involvement, or other confounding medical history that could disqualify them. No other statistical differences were noted.	20 participants aged 18-44 completed the study from the 24 selected and were randomly allocated into 2 groups; 10 that received BFR and 10 that received sham BFR during exercise. 16 males and 4 females age 12-45 were included with a recent (< 6 mo.) ACL injury that did not impede their range of motion or cause significant pain during exercise. Patients were screened for previous musculoskeletal and cardiovascular conditions. No other statistical differences were noted.
Intervention	Leg press with varying resistance by group; either on the dominant leg in the control or the injured leg for ACLR patients. Healthy patients with low load resistance with BFR(NI-BFR) and post-operative patients with low resistance exercise with BFR(ACLR-BFR) performed 1 set of 30 repetitions and 3 sets of 15 at 30% 1Rep Maximum (1RM), with 30 seconds rest between sets. Post-operative patients with high resistance exercise with BFR(BFR-HL) performed 3 sets of 10 repetitions at 70% of their 1RM, with 30 seconds rest between sets. Occlusion pressure was set at a constant 80% arterial pressure.	All participants were trained and instructed to complete 5 sets of 20 repetitions of isometric quadriceps contractions, progressing to knee extensions starting slightly flexed over a bolster, and straight leg raises twice a day. Patients were allowed to add 100 reps per session, or 200 per day. BFR was applied by cuff in 5, 5 minute sets at 130 mmHg and increased by 10 mm every other day to a max of 180 mmHg. A 3 minutes rest period with no BFR was included between sets.	A 16 week rehabilitation program consisted of 20 reps of a lower extremity exercise with a 5-6 second hold, done twice a day. Exercises increased in difficulty and type as rehabilitation progressed; going from straight leg raises and hip adduction to half squats, elastic tube resistance and knee-bending walking. BFR was introduced to the experimental group 2 weeks after surgery at a pressure of 180 mg Hg.	5 preconditioning exercise sessions were spread out evenly 8 days before ACLR, with the last session within 48 hours of surgery. 5 sets of open chain leg extension exercises were completed to failure, and BFR was removed for 90 seconds after the 2 nd and 4 th sets of exercise. Tempo was controlled by metronome and the control group used sham occlusion cuffs. A 10-15 second warm-up was allowed before occlusion was added, and exercises began 30 seconds after the occlusion stimulus was present at 150 mmHg.

	Hughes et al. ⁷	Iverson et al. ⁸	Ohta et al. ⁹	Zargi et al. ¹⁰
Primary outcome	Joint pain rated 0 to 11 after each set and 24 hours post-exercise. Blood Pressure measured pre-exercise and 5 minutes post exercise.	Quadriceps cross sectional area measured by MRI 2 days prior to surgery and 16 days following surgery at 40% & 50% of the femur length, measuring from the patella.	Cross sectional area of the femoral muscles by MRI. Single muscle fiber diameter through biopsy and mathematical average.	Muscles endurance measured by a held contraction in the same position, at 30% established strength. When performance dropped below 90% of this threshold the test was terminated.
Secondary Outcomes	Perceptual muscular exertion measured from 0 to 20 after each set and 24 hours post-exercise. Muscle pain rated 0 to 11 after each set and 24 hours post-exercise.	None	Muscular torque of extensor and flexor groups of the knee measured with isokinetic testing at 60 and 180 degrees/s plus isometric strength at 60 degrees.	Muscle torque measured with a static dynamometer in a sitting position
Results	Perceived exertion was significantly higher in the ACLR-BFR group than the non-injured group ($p < 0.01$), but not different between both ACLR groups. Muscle pain was significantly higher in the ACLR-BFR group than NI-BFR & ACLR-HL by ($p < 0.05$) & ($p < 0.01$) respectively.. Joint pain was significantly reduced in the ACLR-BFR group compared to the ACLR-HL group immediately after the session and at 24 hours. ($p < 0.01$)	No statistical differences were found between the groups for the amount of atrophy present in the quadriceps. This was true for both the male and female participants within each group. ($p = 0.6265$)	Knee extensor strength significantly increased at 60 degrees/s and 60 degrees isometrically by ($p < 0.01$) and extensor cross sectional area increased by a significance of ($p < 0.05$) with some indication that individual muscle fibers from the intervention group hypertrophied more than normal rehabilitation.	Those in the SHAM_BFR group lost significantly more endurance ($p < 0.01$) with a ($p = 0.029$) significant between groups at 4 weeks post-op. This benefit leveled off by the 12-week measure. Continued muscle contraction was better when compared to pre-operation levels and muscle perfusion was markedly higher. ($p < 0.01$)
PEDro Score	8	7	7	9
Conclusions	Perceived exertion was significantly higher in the ACLR-BFR group than the non-injured group, but not different between both ACLR groups. Higher muscle pain was associated with BFR due to compression and ischemia. Joint pain was significantly reduced in the ACLR-BFR group compared to the ACLR-HL group immediately after the session and at 24 hours, indicating reduced joint stress.	Intermittent blood flow restriction training is sufficient to utilize the metabolic benefits ischemia and the related physiological reactions bring about in controlled settings. Increasing resistance rather than repetitions may have undermined the necessary threshold for muscular adaptation.	Increased extensor torque and cross section demonstrate the potential long-term benefits BFR can have when done properly and when combined with a realistic rehabilitation plan for ACLR patients. Long term use of BFR may be more beneficial than short term application.	The effects of a short-term preconditioning sequence of BFR before operation has a beneficial effect on the short-term muscular strength and endurance of the quadriceps muscles when compared to normal pre-habilitation. Increased muscle perfusion indicate promising applications for reducing ischemic damage in surgery.

Implications for Practice, Education and Future Research

The 4 studies included each evaluated using blood flow restriction combined with low resistance exercise into therapeutic intervention plans for patients undergoing anterior cruciate ligament reconstruction.⁷⁻¹⁰ They focused specifically on relevant clinical outcomes such as quadriceps torque and hypertrophy as well as pain and perceived exertion; making them more difficult to compare but providing a fuller picture of multifaceted rehabilitation programs. Hughes et al.⁷ was able to show statistically significant results for joint pain when comparing low resistance exercise and BFR to high resistance exercise and BFR, although this was accompanied by significantly higher levels of muscular pain associated with the treatment.⁷ This low level pain or ache is well documented within BFR as a possible side effect of the local ischemic environment and the tourniquet.⁸ Iverson et al.⁸ was not able to find any significant results when looking at quadriceps atrophy by cross-sectional area, indicating the importance of proper resistance and the potential fragility of different levels of occlusion. Ohta, Zargi and colleagues successfully showed significant improvements in extensor strength and endurance, utilizing BFR post surgically and in preconditioning respectively to prevent atrophy.^{9,10}

The promising aspect of the last 2 studies is their potential for practical application clinically. The rehabilitative protocol Ohta et al.⁹ utilized most closely resembles standard practice for ACLR patients, while Zargi et al.¹⁰ addressed preconditioning before surgery with lasting impacts on the quadriceps. The use of BFR in an extended rehabilitation protocol differed from the short term applications looked at in other studies by following a 16 week plan that would end in correlation with the start of more functional and light sport specific movements.¹¹ The diversity of exercises in this protocol addressed rehabilitation from a more complete standpoint rather than solely focusing on the quadriceps outcomes, increasing resistance and adding exercises consistent with ACLR rehabilitation protocols.³ In contrast to improving muscular adaptations through BFR, Zargi et al.¹⁰ examined hemodynamic responses as well with particular interest to ischemic preconditioning, which can reduce muscular damage and shorten recovery.¹⁰ By implementing BFR in 5 sessions over 8 days prior to surgery, BFR patients showed a rough 50% increase in muscle blood flow whereas SHAM patients experienced a ~30% decrease at 4 weeks post-operation. The effect of this preconditioning is likely heightened by the muscular strength and endurance adaptations, offering the best potential for improved clinical outcomes. It is also much easier to implement clinically as 5 sessions over 8 days, rather than long term application in rehabilitation. More research combining the preconditioning use of BFR and rehabilitative use would be very interesting and promising.

Hughes et al.⁷ analysis of perceived pain and exertion lend good insights into clinical outcomes and patient satisfaction as well. By demonstrating significantly reduced scores for knee pain ($p > 0.01$) they proved that low load exercise does reduce stress on the recovering joint as suspected. The fact that closed chain leg press exercises

were used rather than open chain exercises further increases the practical application as open chain exercises would add even more shear stress. This would be even more relevant to patients receiving bone-patellar tendon-bone grafts as their anterior knee pain is typically higher from stress on the patellar tendon and incision,³ which would be reduced using BFR as well. Increases in muscle pain and perceived exertion were also shown in their study, falling in line with documented symptoms of BFR.

The exercise protocol implemented by Iverson et al.⁷ used some standard therapeutic exercise, but only used body weight for resistance, opting to increase repetitions instead of resistance as the patients progressed. This level of resistance likely fell below the recommended 20-30% 1RM stimulus level for muscular hypertrophy.^{8,12} Increases in endurance may be significant clinical findings as evidenced by Zargi et al.¹⁰, however Iverson et al.⁷ only examined hypertrophy through cross sectional area of the femoral muscles. Small sample size also hurt the design, as a large variety in the amount of atrophy left the results unclear.⁸ The frequency with which they trained may also be detrimental to their design, as meta-analysis showed significantly greater strength and hypertrophy gains when BFR protocol was utilized 2-3 times weekly rather than 4-5 days/week or twice daily as in the study, although this was not in a rehabilitative setting and Ohta et al.⁹ used a similar frequency with positive results.^{9,12} This success of Ohta and colleagues may be attributed to the length of their program, as programs longer than 10 weeks appear to increase muscular strength and hypertrophy more effectively through fiber adaptations and improvement of neuromuscular function.^{9,12}

Each study utilized slightly different protocols for how long to provide the occlusion for during exercise. Intermittent BFR was utilized in three^{7,8,10} of the studies – following a typical program between 90 seconds to 5 minutes of occlusion with periods of reperfusion in between. While not evaluated for rehabilitative use, this pattern of on and off seems to be effective for general training and is becoming one of the most widely accepted protocols.¹³ This intermittent effect is theorized to be the mechanism behind increasing muscle perfusion in the quadriceps through microcapillary formation and resilience.¹⁰ The benefits of using these short bursts on and off is debatable in the protocols used by Iverson et al.⁸ and Hughes et al.⁷ as strength and hypertrophy were measured instead, though the latter was not looking at long term changes. Had the rehabilitation protocol included a significant stimulus for muscle adaptation it would be interesting to see how patients responded to the intermittent stimulus in Iverson et al.'s study.⁸ Analyzing the time of application was difficult for one study⁹ as quantitative data was not shared, however the description of application seemed to indicate leaving the occlusion stimulus on much longer than intermittent protocols, leaving more area for research as this longer stimulus may have contributed to the long term outcomes seen in strength and hypertrophy. Cuff pressure was also variable by study, though all within reasonable values for clinical application. Iverson et al.⁷ increased the pressure by 10 mm Hg every other day as indicated by previous studies, however the effectiveness of this protocol cannot be assessed due to the lack of resistance stimulus.¹ Two studies^{9,10} used moderate blood flow restriction with pressures set at 150 and 180 mm Hg in line with

recommendations for moderate arterial occlusion and indications that increasing pressure above ~130% systolic blood pressure does not increase efficacy of the treatment.^{4,12} Hughes et al.⁷ utilized the only personalized protocol by setting pressure to a constant 80% arterial occlusion with digital adjustments during exercise. Other studies^{8,9} addressed this as a potential threat to their results, realizing that the cuffs may offer variable amounts of restriction. It should be noted that wider cuffs occlude the arterial blood supply at lower pressures than more narrow cuffs due to increased surface area. One aspect of non-variable pressure is that venous or arterial blood may be able to bypass the occlusion stimulus during contraction and therefore affect the level of ischemia and oxidative stress present in the limb, although the effect of this on outcomes is likely minimal as increased pressures are not associated with increased results.^{12,13} While the cuffs in this study were generally fairly wide (11-14 cm), many other studies use more narrow cuffs (5 cm) that are more similar to cuffs found commercially.

The commercial availability of BFR cuffs makes them an easy tool to add to any AT room – but safety protocols must be carefully researched before making decisions as they do not have the safe guards of clinician expertise or being in a healthcare setting. Many options are available for as little as \$20 online, but these offer no pressure gauge to safely determine the level of occlusion, or use elastic compression with no indicators other than patient comfort. These elastic bands usually include instructions to pull until the band feels to be a 7 on a 0-10 scale, with a maximum duration of 20 minutes. This is unsafe as ischemic environments can cause long term damage to tissue, especially those tissues directly under the tourniquet, and clinical application rarely approaches 20 minutes without reperfusion. Using this type of compression increases the potential of complete occlusion, also increasing the risk of developing a thrombus that could cause occlusion post-exercise.¹³ Luckily the stress of low resistance exercise and BFR on the cardiovascular system is low, with increases in diastolic and systolic blood pressure and mean arterial pressure correlating similarly or even less than increases seen with high resistance training.⁷ The effect on stroke volume and cardiac output have also been studied fairly extensively in healthy populations. A slight decrease in stroke volume compensated by an increase in heart rate has been shown, although this response has been shown through mechanical pressure in high resistance training and deemed safe as well.^{13,14} One important aspect of these findings is that they were all shown in laboratory settings with pressure regulated BFR cuffs. Rare symptoms of numbness have increased concern over potential deficits in nerve conduction and health due to ischemia and mechanical pressure, however only present in 1.6% of treatments monitored.¹⁴ Short term studies of nerve function maintain that BFR is safe to implement in short bouts, however the long term neurological effects of using BFR for more than 4 weeks has not been studied and could represent an area for future research.

Using BFR devices with handheld pumps would be the most practical in a rehabilitative setting as they provide pressure feedback and can be adjusted to maximize patient comfort. These types of cuffs are generally wider than elastic versions, which can help to reduce the muscle pain that can be significant for some patients, although these

BFR kits are significantly more expensive(\$300+) which may limit their use in some settings. Some medical companies require training prior to purchasing cuffs, usually in the form of a weekend class or breakout session where practitioners can learn from the most recently published evidence to support their practice. These classes are beneficial to clinical application by adding some regulation and confidence to how techniques are applied, and even the specifics of different style cuffs. Practical application of BFR equipment is the next wave of research that is attempting to address how to implement this technique safely across the profession. The long term outcomes of these techniques need to be assessed as well. An increased correlation of early return from ACLR with osteoarthritis indicates that improving quadriceps strength in patients may be more beneficial to achieve terminal knee extension rather than to achieve an accelerated return to sport.

Beneficial results were shown in 3 of the studies,^{7,9,10} adding to the promising background of research that suggests BFR is an effective technique for increasing muscular strength and size while decreasing joint pain and joint stress in individuals recovering from ACLR. It is generally recommended that BFR be applied with a moderate occlusion pressure that does not completely impede arterial blood flow to the extremity, but the specifics of how to best achieve this will need to be determined through future research, and adapted as necessary to rehabilitative settings. More research is needed on the exercise protocols utilized for rehab to better understand the lower and upper intensity thresholds to ensure the most effective technique. The promising results of using BFR as a preconditioning tool prior to surgery⁹ should be investigated more alone and possibly in combination with therapeutic intervention after surgery as well. Based on the evidence reviewed here, the inconsistencies in application and exercise make it difficult to recommend it over standard high resistance training for patients with ACLR until more standardization and research have been completed. This CAT should be reviewed in 2 years to determine whether additional best-research evidence has been published that could aid in answering the focused clinical question.

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Blood Flow Restriction Training as a rehabilitative Tool in Anterior Cruciate Ligament Reconstruction Patients

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INTRODUCTION

Clinical Scenario

Roughly 150,000 anterior cruciate ligament injuries happen each year, indicating anterior cruciate ligament reconstruction (ACLR) surgery and 6-9 months of rehabilitation to return to play. An early focus of rehabilitation is quadriceps strength and hypertrophy to avoid an extensor lag, but many common open chain exercises to strengthen the quadriceps place significant shear stress on the knee joint and recovering autograph. Blood Flow restriction training may be an effective rehabilitative tool to reduce this stress by combining low load resistance training with an occlusive stimulus to recruit fast twitch muscle fibers, accumulate metabolic compounds and muscle protein synthesis in an anaerobic environment. This type of training has been shown to stimulate muscle growth with much a much lower stimulus threshold than traditional resistance training.

Focused Clinical Question

Does low load resistance training with blood flow restriction effectively improve quadriceps size and pain outcomes in patients undergoing anterior cruciate ligament reconstruction?

METHODS

Terms Used to Guide Search Strategy

Patient/Client Group: Patients receiving Anterior Cruciate Ligament Reconstruction (ACLR)

Intervention: Blood Flow Restriction Training

Comparison: None

Outcome: Pain and strength of the quadriceps muscles

Sources of Evidence Searched

- CINAHL
 - PubMed
- Cochrane Library
 - SportDiscus
- Google Scholar
 - Articles found reviewing related content

Inclusion and Exclusion Criteria

Inclusion

- Utilized low load resistance training with blood flow restriction training
- Pain or atrophy as primary outcomes
- Operative ACLR patients
- Published within the last 10 years (2008-2018)
- Published in English
- Randomized Control Trials

Exclusion

- Studies that examined BFR in post-operative rehabilitation other than ACLR
- Studies that focused on a physiological response other than pain or quadriceps size
- Full text unavailable through Ball State University Databases or Interlibrary Loan

RESULTS

Summary of Search, “Best Evidence” appraised, and Key Findings

4 randomized control trials met the inclusion and exclusion criteria to address the clinical question.

- One study reported a significant increase in knee extensor strength compared to control groups.
- Two studies reported an increase in quadriceps size utilizing BFR while one failed to show this.
- One study reported a decrease in joint pain using BFR.

Best Evidence

Through this search 4 studies were found that met our inclusion criteria with a high enough level of evidence to be considered useful resources towards this topic. They are included in Table 1 and appraised by the Center for Evidence Based Medicine (CEBM) levels of evidence.

Clinical Bottom Line

Blood Flow Restriction training is a promising technique with great potential for rehabilitative success in anterior cruciate ligament reconstruction patients, however more research is needed to determine specific parameters before clinical application can be widely recommended. *Strength of Recommendation: Grade B*

Level of Evidence Number	Study Design/ Methodology	Number Located	Author (Year)
2	Random Control Trial	4	Ohta et al Hughes et al Zhargi et al Iverson et al

	Hughes et al. (2018) ¹	Iverson et al. (2016) ²	Ohta et al. (2017) ³	Zhargi et al. (2018) ⁴
Participants	<ul style="list-style-type: none">30 participants split into 3 groups10 non-injured patients; BFR + low resistance (age 28 ± 5 yr.)10 ACLR patients; BFR + low resistance (age 29 ± 5 yr.)10 ACLR patients; BFR + high resistance (age 31 ± 7 yr.)Hamstring autograph; no other ligamentous involvement or relevant 12 month historyACLR patients included once they could perform a leg press exercise, roughly 3 weeks post-op.	<ul style="list-style-type: none">24 participants randomized into 2 groups (age 18-40 ; 14M, 10F)12 ACLR patients; BFR + body weight resistance (age 24.9 ± 7.4 yr. ; 7M, 5F)12 ACLR patients; body weight resistance (age 29.8 ± 9.3 yr. ; 7M, 5F)Hamstring autograph; no other ligamentous involvement or relevant 12 month historyInjured during sport participationNo statistical differences noted	<ul style="list-style-type: none">44 participants randomized into 2 groups (age 18-52 ; 25M, 19F)22 ACLR patients; BFR + therapeutic ex f (age 30 ± 9.7 ; 12M, 10F)22 ACLR patients; therapeutic ex (age 28 ± 9.7 ; 13M, 9F)Hamstring autograph; no other ligamentous involvement or relevant 6 month historyNo statistical differences noted	<ul style="list-style-type: none">20 participants randomized into 2 groups;10 ACLR patients; BFR + exercise10 ACLR patients; sham + exerciserecent (< 6 mo.) ACL injury that did not impede their range of motion or cause significant pain during exercise.Hamstring autograph; no other ligamentous involvement or relevant historyNo statistical differences noted
Intervention Investigated	Leg press with varying resistance by group; either on the dominant leg in the control or the injured leg for ACLR patients. Healthy patients with low load resistance and BFR and post-operative patients with low resistance exercise and BFR performed 1 set of 30 repetitions and 3 sets of 15 at 30% 1Rep Maximum (1RM), with 30 seconds rest between sets. Post-operative patients with high resistance exercise and BFR performed 3 sets of 10 repetitions at 70% of their 1RM, with 30 seconds rest between sets. Occlusion pressure was set at a constant 80% arterial pressure.	All participants were trained and instructed to complete 5 sets of 20 repetitions of isometric quadriceps contractions, progressing to knee extensions starting slightly flexed over a bolster, and straight leg raises twice a day. Patients were allowed to add 100 reps per session, or 200 per day. BFR was applied by cuff in 5, 5 minute sets at 130 mmHg and increased by 10 mm every other day to a max of 180 mmHg. A 3 minute rest period with no BFR was included between sets 2 and 4.	A 16 week rehabilitation program consisted of 20 reps of a lower extremity exercise with a 5-6 second hold, done twice a day. Exercises increased in difficulty and type as rehabilitation progressed; going from straight leg raises and hip adduction to half squats, elastic tube resistance and knee-bending walking. BFR was introduced to the experimental group 2 weeks after surgery at a pressure of 180 mg Hg.	5 preconditioning exercise sessions were spread out evenly 8 days before ACLR, with the last session within 48 hours of surgery. 5 sets of open chain leg extension exercises were completed to failure, and BFR was removed for 90 seconds after the 2nd and 4th sets of exercise. Tempo was controlled by metronome and the control group used sham occlusion cuffs. A 10-15 second warm-up was allowed before occlusion was added, and exercises began 30 seconds after the occlusion stimulus was present at 150 mmHg.
Outcome Measures	<ul style="list-style-type: none"><i>Pain:</i> muscle and joint measured by 10cm VAS<i>Perceived exertion</i> 11 point RPE scale	<ul style="list-style-type: none"><i>Size:</i> Quadriceps cross sectional area measured at 40 & 50% femur length	<ul style="list-style-type: none"><i>Strength:</i> Knee extensor torque<i>Size:</i> Extensor cross sectional area	<ul style="list-style-type: none"><i>Strength:</i> Knee Extensor torque<i>Endurance:</i> Extension reps
Main Findings	<ul style="list-style-type: none">Joint pain was significantly reduced (95% CI: 1.890 to 0.750, p<0.01)Muscle pain and perceived exertion were higher with BFR (95% CI: 0.292 to 5.058, p<0.05) (95% CI: 2.942 to 7.758, p<0.01)	<ul style="list-style-type: none">No statistical differences in quadriceps size by cross sectional area (p = 0.6265)Body weight resistance likely does not meet stimulus threshold for BFR	<ul style="list-style-type: none">Significant increases in quadriceps strength and size. (p = 0.03)Some increase in fiber size though not significant	<ul style="list-style-type: none">Statistically significant increases in muscle strength and endurance at 4 weeks (p = 0.04)Results leveled off by 12 weeks
Validity Score	9	6	8	8
Conclusions (if any)	BFR effectively strengthens the quadriceps and decreases shear stress, though it may increase muscle pain due to ischemia and mechanical pressure from the cuff.	Low resistance training utilizing body weight of the lower extremity combined with intermittent BFR is not enough to stimulate the quadriceps to hypertrophy.	Increased extensor torque and cross sectional area demonstrate the potential long-term benefits BFR can have when done properly.	The effects of a short-term preconditioning sequence of BFR before operation has a beneficial effect on the short-term muscular strength and endurance of the quadriceps muscles when compared to normal pre-habilitation.

IMPLICATIONS FOR FUTURE RESEARCH

More research is needed on the practical application of BFR, including occlusion pressure, cuff width, time of ischemic stimulus and resistance. It is generally well recommended that BFR be applied with a moderate occlusion pressure that does not completely impede arterial blood flow to the extremity, but the specifics of how to best achieve this in a practical clinical setting will need to be evaluated more thoroughly.

Beneficial results were shown in 3 of the studies, adding to the promising background of research that suggests BFR is an effective technique for increasing muscular strength and size while decreasing joint pain and joint stress in individual recovering from ACLR. The lack of results seen by Iverson et al. (2016) indicate that previous research stating strength gains from a 10% 1RM stimulus

The extent of muscle pain due to the ischemic environment has been well studied and at this time poses no additional safety concern to the patient, though it has been significant enough to prompt participants to drop out of studies and could be remedied by more comfortable cuffs or slightly lower occlusion pressure.

The promising results of using BFR as a preconditioning tool prior to surgery should be investigated more alone and possibly in combination with therapeutic intervention after surgery as well. Seeing significant results 4 weeks post op. are very encouraging, and if BFR could be continued the results may outlast the leveling off seen at week 12.

IMPLICATIONS FOR PRACTICE

Due to inconsistent treatment parameters, results and concerns for practical application, BFR cannot be recommended as a rehabilitative tool until further research addresses these.

REFERENCES

- Hughes, et al. Comparison of the acute perceptual and blood pressure response to heavy load and light load blood flow restriction resistance exercise in anterior cruciate ligament reconstruction patients and non-injured populations. Physical Therapy in Sport 33 (2018)54,61.
- Iversen E, Rostad V, Larmo A. Intermittent blood flow restriction does not reduce atrophy following anterior cruciate ligament reconstruction. J Sport Health Sci. 2016;5(1):115–118.
- Ohta H, Kurosawa H, Ikeda H, Iwase Y, Satou N, Nakamura S. Low-load resistance muscular training with moderate restriction of blood flow after anterior cruciate ligament reconstruction. Acta Orthop Scand. 2017;74(1):62–68.
- Žargi T, Drobnič M, Stražar K and Kacin A. Short–Term Preconditioning With Blood Flow Restricted Exercise Preserves Quadriceps Muscle Endurance in Patients After Anterior Cruciate Ligament Reconstruction. Front. Physiol.2018;9:1150.

Blood Flow Restriction Training as a Rehabilitative Tool for Anterior Cruciate Ligament Reconstruction Patients

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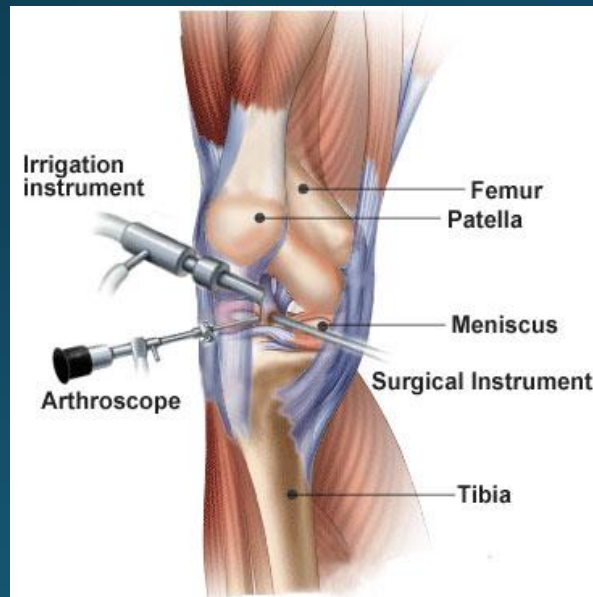
ACL Injuries & Blood Flow Restriction

Blood Flow Restriction Training

- Complete venous occlusion & moderate arterial occlusion via inflatable cuff
- Increased Type 1 Fiber Recruitment
- Strength gains relative to high resistance exercise



<https://mtipt.com/blood-flow-restriction-bfr-training/>



<http://canacopegdl.com/keyword/hamstring-acl-reconstruction.html>

ACL Background

- 150,000 per year¹
- 6-9 months rehab; focus on quad strength and hypertrophy
- Extensor strength significantly affects long term outcomes
- High shear stress on joint and tendon graft in rehab

Does low load resistance training with blood flow restriction effectively improve quadriceps size and pain outcomes in patients undergoing anterior cruciate ligament reconstruction?

Search Terms

- P : operative ACLR patients
- I : BFR AND resistance exercise/training
- C : Control or sham BFR
- O : pain or atrophy/hypertrophy

Databases

- CINAHL
- PubMed
- SportDiscus
- Cochrane Library
- Literature found in related content

Inclusion Criteria

- Utilized low load resistance training with blood flow restriction training
- Participants were ACLR patients
- Quadriceps strength or size or pain as primary outcomes
- RCTs published within the last 10 years (2008-2018)
- Published in English

Exclusion Criteria

- Examined BFR for other conditions
- Focus did not include quadriceps strength or size or pain
- Non-human trials
- Full Text unavailable

Best Evidence

- 4 randomized control trials met the inclusion and exclusion criteria to address the clinical question.^{2,3,4,5}

Level of Evidence	Study Design	Number Found	Reference
2	Randomized Control Trial	3	Hughes et al. Ohta et al. Zargi et al. Iverson et al

- One study reported a significant increase in knee extensor strength utilizing BFR when compared to control groups.⁴
- Two studies reported an increase in quadriceps size utilizing BFR,^{4,5} while 1 study utilizing intermittent BFR did not.³
- One study reported a decrease in perceived pain when using low intensity training with BFR compared to a healthy population and a high intensity regiment for ACLR patients.²

Iverson et al. (2017)

24 participants

BFR + Therapeutic Exercise

Age 24.9 ± 7.4 years ; 7M & 5F

Therapeutic exercise alone

Age 29.8 ± 9.3 years ; 7M & 5F

Rehabilitation Protocol

- Isometric quadriceps contractions
- Knee extension
- Straight Leg Raises
- 5x20 twice a day; adding ≤ 100 repetitions per session, or 200 daily

BFR Protocol

- 14 cm wide hand inflated cuff
- 5 min. on 3 min. off done 5 times

Outcomes

- Quadriceps CSA at 40% & 50% femur length

Results

- No significant reduction of atrophy ($p = 0.6265$)



Hughes et al. (2016)

30 participants

BFR + low load RT (ACLR-BFR)
age 31 ± 7 years

High Load RT (ACLR-HL)
age 28 ± 5 years

BFR + high load RT (NI-BFR)
age 29 ± 5 years

Rehabilitation Protocol:

- 5 min. cycling, 10 leg presses, 5 min rest
- Leg press $4 \times 30, 15, 15, 15$ @ 30% 1RM
- Leg press 3×10 @ 70% 1RM

BFR Protocol

- 11.5 cm wide digitally cuff
- Constant 80% occlusion

Outcomes:

- Perceived pain and exertion (RPE & RPP)
- Blood pressure response

Results:

- Higher exertion in ACLR-BFR to NI-BFR ($p < 0.01$)
- Higher muscle pain in ACLR-BFR to NI-BFR ($p < 0.05$)
& ACLR-HL ($p < 0.01$)
- Higher muscle pain in NI-BFR to ACLR-HL ($p < 0.01$)
- Lower knee pain in ACLR-BFR to ACLR-HL ($p < 0.01$)
- No blood pressure changes between groups

Ohta et al. (2008)

44 participants

BFR + therapeutic exercise
age 28 ± 9.7 years ; 13M & 9F

Therapeutic exercise alone
age 30 ± 9.7 years ; 12M & 10F

Rehabilitation Protocol

- SLR & hip abd. 2x20 (weeks 1-8)
- Hip add. 2x2 (weeks 1-12)
- Half Squat 2x20 (weeks 5-16)
- Step ups 3x30 (weeks 5-16)
- Elastic tubing 1-2x20 (weeks 9-13 & 13-16)
- Knee bending walking 3x60 (weeks 13-16)

BFR Protocol

- Hand pumped tourniquet
- 180 mm Hg occlusion pressure

Outcomes

- Cross Sectional Area (CSA) of femoral muscles
- Single muscle fiber type and size
- Muscular torque by isokinetic testing

Results

- Significant increase knee extensor CSA ($p = 0.04$)
- Increase in fiber size though not significant
- Significant increase in extensor strength:

	60°	Isometric 60	180°
torque	$p < 0.001$	$p < 0.001$	$p = 0.004$

Zhargi et al. (2018)

20 participants

BFR + Therapeutic Exercise
5 dominant legs & 5 non-dominant

SHAM + Therapeutic Exercise
5 dominant legs & 5 non-dominant

Pre-habilitation Protocol

- 6 sets of knee extension to failure

BFR Protocol

- 14 cm wide digitally inflated cuff
- 150 mm Hg

Outcomes

- Quadriceps strength and endurance
- Blood flow in the quadriceps

Results

- Reduced endurance in SHAM-BFR ($p < 0.001$)
- Significant difference between groups ($p = 0.029$)
- Significant increase in muscle perfusion ($p < 0.001$)



<http://www.prehabexercises.com/>

	Iverson	Hughes	Ohta	Zhargi
Pain		✓		
Quadriceps Size	✗		✓	✓
Quadriceps Strength			✓	✓
Other		Blood Pressure	Fiber Type Hypertrophy	Muscle Perfusion

Discussion

Mixed results

BFR cuff and parameters

Practical similarities of rehab protocol

General safety



https://www.themanualtherapist.com/2017/05/blood-flow-restriction-bfr-training_11.html



<https://www.owensrecoveryscience.com/campaigns/blood-flow-restriction-and-cycling/>

YOUR GUIDE TO BLOODFLOW RESTRICTION TRAINING

WHERE TO WRAP



DO

- Wrap at the top of the arm or leg only.
- You can wrap your arms for shoulder or chest workout or your legs for glutes. Just use your head and keep weights light!

DON'T

- Don't wrap at the knee for calf training or at the elbow for forearms. Wrap high on the leg or arm.
- Wrap for any lift above 50% of your 1RM. 20-40% is the sweet spot.

HOW TO WRAP



DO

- Use a narrow (5-9 cm) cuff or bandage to reduce the risk of occluding the arteries.
- Wrap in layers.
- Use ace bandages, narrow tourniquets, or knee wraps.

DON'T

- Use wide (>10 cm) blood pressure cuffs.
- Wrap in a spiral fashion covering a large amount of the limb.

HOW TIGHT TO WRAP



DO

- Aim for 6-7 tightness on a scale of 10.
- Feel OK: erring on the side of "a little too loose." 40 and 80% occlusion have shown the same level of muscle and strength gains!

DON'T

- Wrap to the point where you feel numbness or tingling.
- Wrap so tight that you have trouble performing more than a few reps. High reps are (at least 15 per set) are the norm for BFR!

Clinical Bottom Line

At this time I am unable to recommend BFR for widespread clinical use due to the need for further research on application parameters and the safety of practical application in clinical settings. I do expect BFR to grow in popularity and be around in the coming years.

Strength of Recommendation: Grade B

Questions?

References

- 1. Hughes, et al. Comparison of the acute perceptual and blood pressure response to heavy load and light load blood flow restriction resistance exercise in anterior cruciate ligament reconstruction patients and non-injured populations. *Physical Therapy in Sport* 33 (2018)54,61.
- 2. Iversen E, Rostad V, Larmo A. Intermittent blood flow restriction does not reduce atrophy following anterior cruciate ligament reconstruction. *J Sport Health Sci.* 2016;5(1):115– 118.
- 3. Ohta H, Kurosawa H, Ikeda H, Iwase Y, Satou N, Nakamura S. Low-load resistance muscular training with moderate restriction of blood flow after anterior cruciate ligament reconstruction. *Acta Orthop Scand.* 2008;74(1):62–68.
- 4. Žargi T, Drobnič M, Stražar K and Kacin A. Short-Term Preconditioning With Blood Flow Restricted Exercise Preserves Quadriceps Muscle Endurance in Patients After Anterior Cruciate Ligament Reconstruction. *Front. Physiol.* 2018;9:1150.